Study of variants to classical mechanical exhaust ventilation systems by using mechanical exhaust in habitable rooms

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ABSTRACT

Nowadays, due to the higher energy performance of dwellings, ventilation plays an increasing role in maintaining a good indoor comfort. Therefore new ventilation strategies in combination with demand controlled ventilation are needed to accomplish high energy-efficient ventilation (limiting ventilation losses and auxiliary energy consumption) while providing good indoor air quality, thermal and acoustic comfort.

The classic ventilation approach of mechanical extract is based on air supply in the living rooms which is transferred towards the wet or functional rooms where the air is extracted. In this paper a modification on this principle is presented with natural air supply in the living rooms and mechanical extraction in bedrooms (night zone) or each room.

By means of different simulation studies the performance of these ventilation strategies combined with demand controlled is compared in terms of indoor air quality and average air flow rates according to different national methodologies (Belgium and France). The evaluation of the indoor air quality is based on the exposure to CO_2 and relative humidity in the rooms.

Besides simulations, results of an in-situ measurement campaign of a ventilation system according to the modification are presented.

It is found that by applying the modified ventilation strategies a remarkable better indoor air quality and even a more energy efficient ventilation -compared to the classic ventilation approach- can be achieved.

KEYWORDS

Demand controlled ventilation, extraction from habitable rooms, simulation, in-situ measurement

1 INTRODUCTION

On continent Europe, demand controlled ventilation (DCV) as well as heat recovery (HR) are usually applied to realize energy efficient mechanical ventilation systems (MV). For the moderate climate zone of Western Europe, with about 2500–3000 heating degree days, the payback time for investments in heat recovery ventilation is long, especially in buildings with relatively low air change rates such as dwellings. Due to its competitive price setting, low electricity cost as well as due to reports in popular media and scientific literature about possible health risks associated with heat recovery systems, simple central MEV dominates the residential ventilation market in this region. The great variability of a dwelling occupancy in time and place, enhances the potential of DCV. By applying DCV, heating energy related to ventilation is reduced by 20 to 50%, while electricity consumption is similarly reduced (Pollet, et al., 2013).

The critical zones with respect to IAQ within the dwelling are the bedrooms, due to its long occupancy period and limited volume, enforced by possible small air flow rates caused by noise complaints or low pressure levels. Adding a mechanical extraction to these habitable rooms equipped with natural air supply (in case of MEV systems) could improve IAQ. The aim of this paper is to assess theoretically as well as experimentally, the energy saving potential and the indoor air quality (IAQ) to which the occupants of the dwelling are exposed when applying a DCV system consisting of natural air supply and mechanical extract from each room, compared to normative demand controlled MEV systems which only extract in the wet rooms. The impact of mechanical extraction in the living room instead of natural supply was also analysed. The theoretical comparison is done in a Belgian and French context.

2 SYSTEM DESCRIPTION

The demand controlled systems considered were (see Figure 1):

- (REF) natural air supply in all habitable rooms and demand controlled mechanical extraction in wet rooms
- (1) natural air supply in all habitable rooms and demand controlled mechanical extraction in each room (both wet and habitable)
- (2) natural air supply only in the bedrooms (night zone) and demand controlled mechanical extraction in each room (both wet and habitable)

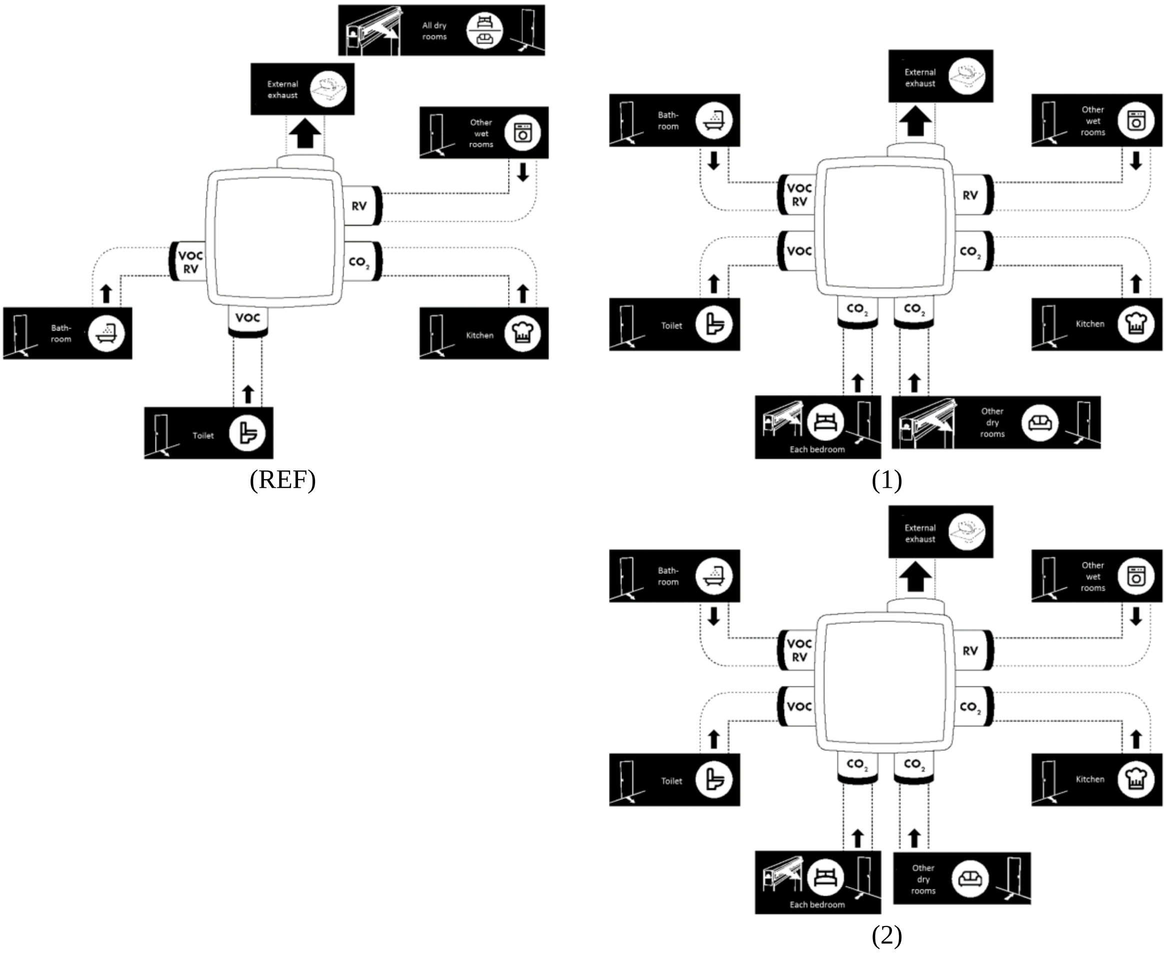


Figure 1: Considered ventilation systems (sensors for Belgium)

3 METHODS

3.1 Simulations

The different ventilation systems were simulated in the national indicated softwares and the IAQ performance was checked according to the national criteria (see Table 1).

Table 1: Country specific parameters

<table>
<tr><th></th><th>Belgium</th><th colspan="5">France</th></tr>
<tr><td>Software</td><td>Contam</td><td colspan="5">MATHIS or TRNSys-Contam</td></tr>
<tr><td>CO_2 criterion</td><td>[ppm.h cumulative]
Base: Δ600 ppm
Threshold: 100.10^3 ppm.h per person</td><td colspan="5">[ppm.h per room]
Base: 2000 ppm
Threshold: 400.10^3 ppm.h per room</td></tr>
<tr><td>CO_2 control</td><td>Δ400 – 600 ppm for
$q_{min – max}$ = 3 – 30 m³/h</td><td colspan="5">1600 - 2000 ppm for
$q_{min – max}$ = 1 – 30 m³/h</td></tr>
<tr><td></td><td>3 bedroom detached single family house with a pressure controlled 2 Pa air inlet</td><td colspan="5">3 bedroom detached single family house (F3) with a humidity controlled 20 Pa air inlet (hygro B)</td></tr>
<tr><td rowspan="4">CO_2 control in case of inversion study</td><td rowspan="4"></td><td></td><td><1000</td><td>>1000</td><td>>1500</td><td>>2000 ppm</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td>5 m³/h</td></tr>
<tr><td>2</td><td>0</td><td>0</td><td>5</td><td>10 m³/h</td></tr>
<tr><td>3</td><td>0</td><td>5</td><td>10</td><td>15 m³/h</td></tr>
</table>

Air flow rates were compared to reference ventilation systems. Furthermore, possible reserve flow of indoor air to the habitable rooms was investigated. Generally, and especially in France, regulation states that the air circulation must appear fundamentally from the habitable rooms to the wet rooms. Therefore, the reverse air flow rate through the doors and/or the origin of the air that flows to the wet rooms were investigated. This research was done by reproducing the MATHIS hypotheses in a TRNSys-CONTAM coupling. Three different CO_2 control strategies in the bedroom were analysed as listed in Table 1. The output was the frequency of inverted air flow through the bedroom doors.

3.2 In-situ measurements

In a 4 bedroom detached single family house in Belgium equipped with a demand controlled MEV system, CO_2 measurements were carried out in the main bedroom (2 persons). Bedrooms were equipped with a CO_2 controlled mechanical extract in addition to the natural supply. During the first week the extract ventilation rate in the main bedroom was proportionally controlled on CO_2 between 800 and 1000 ppm for minimum and maximum air flow rates of 3 and 30 m³/h respectively. During the second week the extract ventilation in the bedrooms was switched off to compare with a reference MEV system.

4 RESULTS

4.1 Simulations

In any of the simulations performed, the relative humidity levels in the wet rooms complied with the national criteria set for those rooms. The results of the Belgian simulations are shown in Figure 2 where the IAQ is traded off against the ventilation losses for the three ventilation strategies considered. It is clear that

- Extracting from habitable rooms (1) and (2) has a positive impact on the IAQ compared to the reference system, since CO_2 exceeds above Δ600 ppm are negligible.
- When there is no natural air supply present in the living room (2) IAQ stays excellent due to the mechanical extract in the living room and the air transfer from the (unoccupied) bedrooms with natural air supply. Moreover, due to more air transfer rates in the dwelling, the ventilation losses are smaller compared to (1).

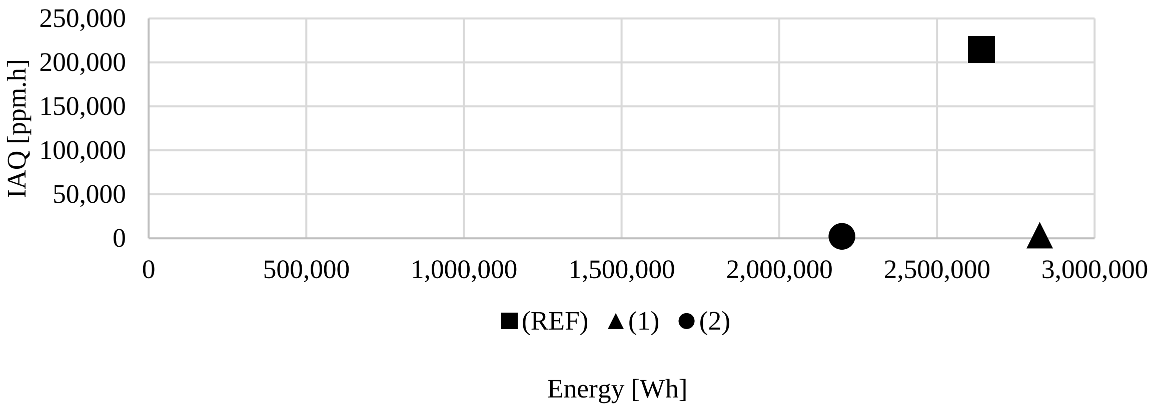


Figure 2: Belgium

The results of the French simulations are summarized in Table 2. Cumulative exposure to CO_2 concentrations above 1200 and 2000 ppm are listed. Bearing in mind that the CO_2 is controlled on a threshold of 2000 ppm, the exposures to levels above 1200 ppm are quite high. Due to the extraction directly from the bedrooms (and not from the living room), cumulative exceeds of 2000 ppm CO_2 are not found in contrast to the reference system, similar to the effects found in the Belgian simulations. However, the cumulative exceeds of 1200 ppm are even higher with extraction from the bedrooms. This can be explained by a humidity controlled extraction from the wet rooms at lower mean air flow rates for configuration 1 compared to the reference (as simulated).

Table 2: France [kppm.h]

	CO_2 threshold	**Living room**	**Room 1**	**Room 2**	**Room 3**
(REF)	1200 ppm	1375	1752	1408	0
	2000 ppm	0	283	170	0
(1)	1200 ppm	1662	2168	3349	0
	2000 ppm	122	0	0	0

The average air flow rate in case of extraction from the habitable rooms was not necessarily higher than in the reference case, due to smart controlled ventilation according to the needs.

The results of the examination of the inverted air flow rate through the bedroom doors in France are summarized in Table 3 for different controlled strategies of the bedroom extraction (no living room extraction). It shows the percentage of time inverted air flow rates are observed.

Table 3: Inverted air flow frequency

	Bedroom door 1		Bedroom door 2	
	All time	**Occupied**	**All time**	**Occupied**
(REF)	1.0	0.6	1.8	1.2
(1) 1 threshold	3.2	0.7	4.2	2.2
(1) 2 thresholds	3.9	2.0	4.5	2.3
(1) 3 thresholds	4.3	2.7	5.8	4.3

The augmented percentages in the case of (1) are also associated with higher cumulative flows due to extract from the bedrooms. In the reference case inversions also occur due to wind and thermal effects that are higher than the mechanical extract forces. Adding extract in the bedrooms implies an inversion part induced by the mechanical extract in the bedroom. However, the level of reversed flow is limited and can be restricted by adjusting the total extract rate from the wet rooms compared to the one from the bedrooms. In any case the instantaneous total extract from wet rooms should be higher than the extract rate from bedrooms to restrict backflow.
It’s important to note that at the wet and functional rooms, there is no inversion at all. Pollution risk from toilets, bathroom or kitchen is not present. Moreover the inversions occur -as for the reference- only when the humidity and as a consequence the air flow rate in the wet rooms is low. It was also found that when a CO_2 controlled extraction is present in any habitable room, living rooms as well as bedrooms, negligible CO_2 loaded reversed air flow rate will occur.

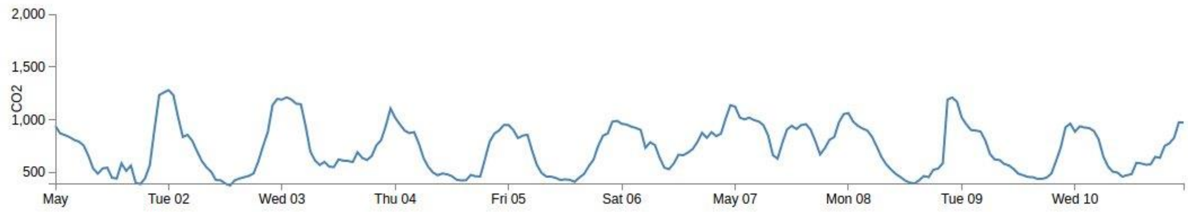
As a conclusion about the occurrence of reversed flow one can state:

- An increase in inversions, depending on the extraction in the wet rooms compared to the bedrooms, is observed.
- Frequency of occurrence remains low (below 6%) for this housing configuration, compared with 2% for the base case, or even less than 4.5% compared with just under 1% during occupation.
- The inversions are observed systematically for low relative humidity in the wet rooms.
- There is no evidence of inversion in the wet rooms.
- The inversions make more use of the air inlets of the living room and permeability of the common rooms (living room and hall).
- Extraction in any habitable and wet room, also prevents inversion at the transfer openings of doors.

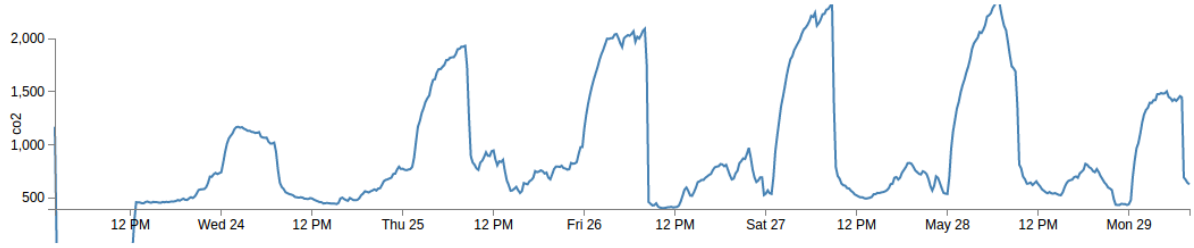
If mechanical extraction is present in the habitable room, the natural supply in this habitable room can be dimensioned smaller, with consequences on thermal as well as acoustic comfort. In that way, high performance MEV systems can be designed.

4.2 In-situ measurements

Measurement results in a 2 person bedroom equipped with CO_2 controlled extract are plotted on Figure 3. CO_2 concentrations never exceed 1200 ppm and decrease to outdoor concentration during inoccupancy. When the natural air supply is closed and the extract ventilation is turned off each night the CO_2 concentrations exceed 2000 to 2500 ppm (excepts for the first night when only one person was present in the bedroom).



(a) with natural air supply and mechanical extract ventilation



(b) without natural air supply and without mechanical extract ventilation

Figure 3: CO_2 concentration in 2 pers. bedroom

5 CONCLUSIONS

Based on 2 building simulation tools of Belgium and France, an improved mechanical extract ventilation system with extraction from bedrooms (or all habitable rooms) showed better performance concerning IAQ in the habitable rooms, while mean air flow rates are similar to the reference case due to smart ventilation. Simulation tools provide the evidence to recognize innovative concepts within energy performance regulations.

6 REFERENCES

Pollet, I. et al., 2013. Performance of demand controlled mechanical extract ventilation system for dwellings. *Journal of sustainable engineering design*, 1(3).